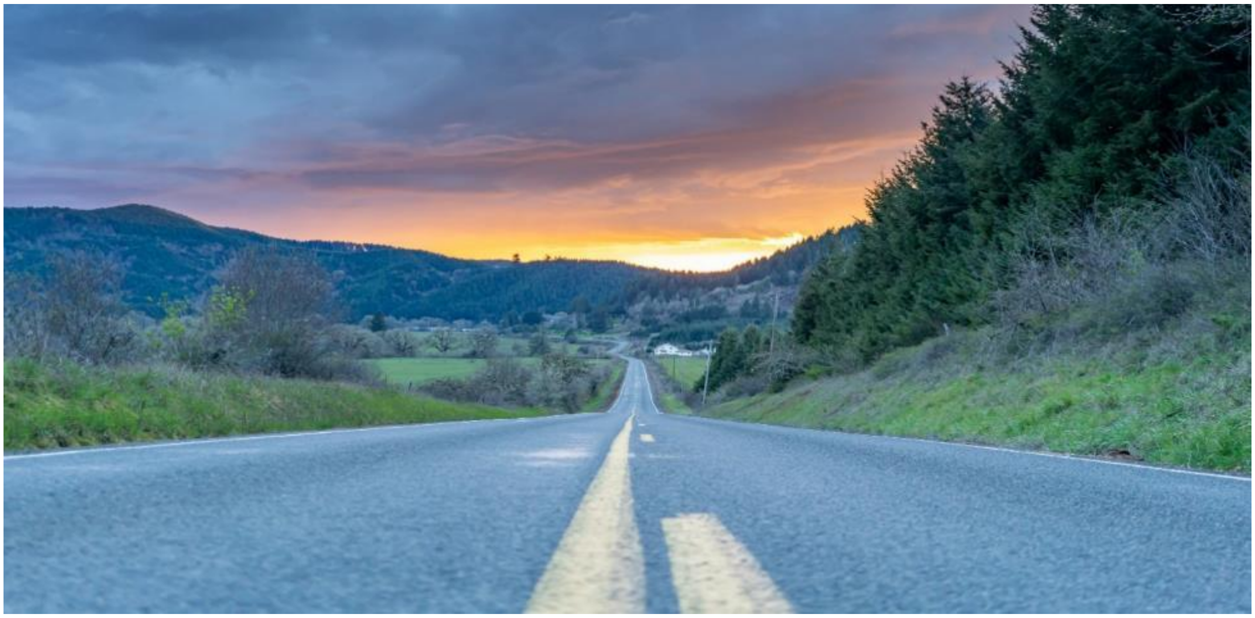
Chapter 11 - Rock Cuts – Analysis, Design, and Mitigation



Chapter Contents

11.1 General

This chapter discusses the analysis, design guidelines, and standards for rock slopes adjacent to highways. Rock slope design for material sources is discussed in Chapter 8.

11.2 ODOT Rock Slope Design Policy

The purpose of the policy is to establish slope design standards for rock cuts and to encourage the active involvement of geologists and geotechnical engineers in the rock slope design process. This involvement is intended to ensure that rock slopes are safe to construct and economical and will optimize safety for the public. In general, the policy includes four sections that deal with rock slopes. These sections cover the rock slope design, rock fallout area requirements, the use of benches, and rock slope stabilization and mitigation techniques.

11.2.1 Rock Slope Design

The purpose of the rock slope design is to develop rock cuts that will be safe to construct and will provide long-term safety for the public. The inclination of rock slopes should be based on the structural geology and stability of the rock units, as described in the Geology or Geotechnical Report. Rock unit slopes of vertical, 0.25:1, 0.5:1, 0.75:1 and 1:1 are commonly considered. The design rock cut slope should be the steepest continuous slope (without benches) that satisfies physical and stability considerations. Controlled blasting (using presplit and trim blasting techniques) is required for rock cut slopes from vertical to 0.75:1. The purpose of controlled blasting is to minimize blast damage to the rock backslope to help insure long-term-stability, improve safety, and lessen maintenance. See Section 11.5 for more details regarding rock slope design.

11.2.2 Rock slope Fallout Areas

Fallout areas should be used where hazardous rock fall could occur. The fallout area is a non-traveled area between the highway and the cut slope with minimum width, depth, and slope requirements. The minimum dimensions should be determined based on slope inclination and height. The depth of the fallout area varies with the slope configuration. A preliminary determination of the fallout area or catch ditch dimensions can be obtained from the Ritchie Rock fall Catch Ditch Design Chart located in the *ODOT Highway Design Manual, section 10.4*.

Final catch ditch dimensions should be determined using the *Rock fall Catchment Area Design Guide* (FHWA Final Report SPR-03(032).

As noted in the 2003 *ODOT Highway Design Manual, section 10.4.4*, a goal of 90% retention of rock in the catchment area has been adopted for all new and reconstructed rock slopes. In addition, a goal of 99% retention of free falling rocks is also recommended. These goals may not be achievable in all cases due to cost, environmental reasons, or other factors. In these cases additional stabilization measures such as draped mesh and rock bolting should be evaluated.

The retention goals should also be considered with respect to the nature of the rock slope and rockfall activity that occurs at the individual site. Low-frequency/high impact sites, areas of heavy traffic, or unfavorable roadway geometry may necessitate higher retention. Since rockfall mitigation projects are commonly funded to a preset budget, designs for a lower than optimal containment may result. This should not discourage designers from improving the situation at a hazardous rock slope even if the value is less than the adopted goal if the increased retention is cost-effective. Projects that partially mitigate rockfall hazards should be constructed so that future efforts at greater retention are not inhibited.

The catchment area depth may be achieved in a number of ways, including excavation and/or placing suitable retaining structures at the highway shoulder. Where the slopes are inclined at flatter than 0.75:1, and where the anticipated size of a single rock is less than 2 feet in diameter, chain link catch fences may be considered as a substitute for depth of fallout. Slopes less than 40 feet high and flatter than 1:1 generally have a ditch and recoverable slope equal to or greater than a fallout ditch shown in the Rock fall Catchment Area Design Guide. In that case, the standard roadway ditch will serve as adequate rock fall catchment. For rock slopes greater than 80 feet, the designer should use rockfall simulation programs discussed in Section 11.3 and ditch design guidelines discussed in 11.4.2.

Temporary detours may require the construction of rock slopes and fallout areas. If the site has previously been an area of rock fall activity, and the detour will reduce the fallout area, thereby putting motorists in increased risk, the rock slope and fallout area must be designed to, at a minimum, not increase the risk to the public. Fallout areas should then be designed to capture or retain at least as much rock fall as was previously available prior to construction. Additional mitigation measures, along with one-way travel, reduced travel speed in the rock fall zone, and increased sight distances may be required to reduce risk to the public. The designer should be prepared to address all of these issues in the design process.

11.2.3 Benches

For most rock slope designs, benches should be avoided. The need for benches will be evaluated in the geology and geotechnical investigations and described in the resulting reports. The minimum bench design should satisfy the requirements outlined in the Rock fall Catchment Area Design Guide. The bench configuration may be controlled by the need to perform periodic maintenance, which requires access to the bench. Soil and rock slopes may need a modification with benches to conform to the environment or for safety and economic concerns. Following are some appropriate bench applications.

- Benching may improve slope stability where continuous slopes are not stable.
- Where maintenance due to sloughing of soil overburden may be anticipated, a bench will provide access and working room at the overburden rock contact.
- Developing an access bench may facilitate construction where the top of cut begins at an intermediate slope location.
- On very high cuts, benches may be included for safety where rock fall is expected during construction.
- Where necessary, benches may be located to intercept and direct surface water runoff and groundwater seepage to an appropriate collection facility.
- All benches should be constructed to allow for maintenance access.

11.2.4 Rock Slope Stabilization and Rockfall Mitigation Techniques

Rock slope stabilization techniques may be required to accommodate special geologic features. Stabilization techniques include rock bolts and dowels, wire mesh and cable net slope protection, flexible and rigid rock fall barriers, reinforced shotcrete, trim and production blasting. Specific stabilization techniques with appropriate design will be recommended in the Geotechnical Report as necessary. Refer to Section 11.4 for more detail.

11.3 Rock slope Stability Analysis

Slope stability analysis for rock slopes involves a thorough understanding of the structural geology and rock mechanics. Only geotechnical practitioners experienced in collecting and analyzing rock structure data should perform these functions. For most rock cuts on highway slopes, the stresses in the rock are much less, than the rock strength so there is little concern with the fracturing of the intact rock. Therefore, stability is concerned with the stability of rock blocks formed by the discontinuities. Field data collection of the dip, dip direction, nature, and type of joint infilling, joint roughness and spacing are important for the stability analysis of planar, wedge and toppling failure modes. Slope height, angle, presence of potential rock launching features, block size, and block shape are important for the analysis and design of rock fall mitigation techniques. Hand-calculation methods can be used to analyze potential planar and wedge failures and computer programs such as Rocscience DIPS, SWEDGE, RocTopple, and ROCPLANE are available. Rock fall simulation programs, such as CRSP (Colorado Rock fall Simulation Program) or RocFall, are used to analyze for rock fall catchment size and the prediction of rock kinetic energy. Only geotechnical practitioners experienced in using these programs should perform the analysis. There are several references available for details on design, excavation, and stabilization of rock slopes including Wyllie and Mah, 1998.

11.4 Design Guidelines

General design guidelines are found in the references listed in Section 11.7. Design of rock slopes adjacent to ODOT highways must also include consideration of additional factors such as environmental issues, history of rockfall hazards, cost, risk/benefit, and needs of the project. The following guidelines provide information on ODOT rock slope design.

11.4.1 Geologic Investigation and Mapping

For projects that include rock cuts, the geotechnical designer should contact the local Maintenance district office to discuss, the history of past rock fall events and consult the Region Geologist for the project area to determine the Unstable Slopes System score and priority for that highway and for the Region. The designer should also discuss the geologic hazard potential with the Region Geologist so that a consensus on the degree of rock fall potential is reached. The discussions will serve to highlight concerns regarding construction, local environmental needs, and feasible options for mitigation of the hazard. The development and implementation of the geologic investigation can then be completed.

Field data collection is generally done on a project site-specific basis. Wiley and Mah, 1998, discusses joint mapping techniques, stereographic projection, and types of subsurface exploration that may be performed on rock slopes. Full-scale tests of rock fall at the site may also be performed, however, the cost and practicality of traffic control generally prevents this type of work.

11.4.2 Analysis and Design

As previously stated, analysis of planar, wedge and toppling failure modes can be performed by hand or with some available computer programs. Wiley and Mah, 1998, discusses the analysis in detail.

Simulation of rock fall using the CRSP or RocFall computer program may be needed to determine the minimum required dimensions of a rock fall catch ditch and the kinetic energy of rocks that may need to be restrained by barriers, wire mesh, screens, or walls. As a rule of thumb, draped gabion wire or 0.079 to 0.118 in (2 mm to 3 mm) high tensile strength mesh slope protection and screens are capable of withstanding impacts from rocks up to 2 feet in diameter. For larger rocks, up to 4 to 5 feet, cable net or heavier gauge high tensile strength wire mesh (0.157 inch, 4 mm) should be used. Alternatively, proprietary flexible rock fall barrier systems, attenuator systems, or retaining walls should be considered. Experience with the Rock fall Catchment Areas Design Guide study indicates that rock fall catch areas wider that 30 to 35 feet are not typically cost effective to construct, and additional barriers, fences or walls to gain ditch depth become more cost effective than wider ditches.

11.4.3 Construction Issues

Construction of rock slopes near highways frequently must consider traffic control during blasting and scaling operations. The traffic control may include adjacent railroad facilities where trains are running next to the highway or other adjacent structures and facilities. The cost of traffic control for a busy highway can potentially result in a doubling of the project cost. Therefore, careful consideration of staging, detours, work zones, and blast-produced fly rock control must be done during design. It may even be necessary to choose another mitigation option than the preferred one because of these issues.

Environmental concerns in scenic highway corridors have made construction of rock slopes more difficult. Presplit whole half-casts that are visible after blasting may be regarded as a visual concern and a bid item may be needed to partially or completely remove them. This issue has been most notable in the Columbia River Gorge Scenic Corridor, and in a few USFS forest highways. Rock coloration has also been a concern and a bid item for Permeon, a rock coloration product, has been included on several projects contracts. In addition, sculpted shotcrete could be considered as a mitigation alternative for visual impacts on some slopes.

11.4.4 Blasting Consultant

A Blasting Consultant may need to be retained to assist a contractor in designing a safe blast if there are nearby structures, if the site is particularly challenging, or otherwise has the potential to result in undesired consequences. Guidelines for determining when a Blasting Consultant is needed are located on the ODOT website. ODOT keeps a list of preapproved blasting consultants and has a method of approving new blasting consultants and the HQ Geotechnical Group should be contacted.

11.4.5 Wire Mesh Slope Protection/ Cable Net Slope Protection

For draped wire mesh slope protection, the designer may choose either double twisted gabion wire mesh or high tensile strength wire mesh. These systems are typically either galvanized or PVC coated. Staining and powder coating of the system can address visual impacts associated with the mesh. Heavier gauge high tensile strength wire mesh is an alternative to cable net systems. Anchor spacing for Wire Mesh, Cable Net, and Post-Supported Wire Mesh Slope Protection are based on the weight of the mesh alone. Narrower spacing may be required where snow and ice loads will add a significant amount of stress to the anchors. Anchor embedment guidelines are provided on the standard details however, specific requirements should be developed on a site-specific basis.

The WashDOT research report, *Design Guidelines for Wire Mesh/Cable Net Slope Protection, WA-RD 612.1*, should be used to determine anchor spacing in snow/ice load situations. If mesh is use in a coastal environment, stainless steel fasteners and hardware or heavy galvanizing should be used to inhibit corrosion.

11.4.6 Rock Reinforcing Bolts and Rock Reinforcing Dowels

The designer must identify the installation area, size and strength of steel, pattern, or spacing, inclination, minimum length, and design loads of the bolts or dowels and this information must be included in the Geotechnical Report. Non-shrink cement grouts should be used for all permanent application of rock reinforcing bolts and dowels. Polyester resin or cement grout should only be considered for semi-permanent rock reinforcing dowels. Hollow bar anchors are becoming more common due to their relatively easy installation and ability to be installed in poor ground conditions. Mechanical anchorage bolts and non-shrink cement grout are included in the *ODOT Qualified Products List (QPL)*. The designer should refer to minimum rock strength requirements required by the manufacturer for mechanical anchorage bolts. Split set and bail set type anchorage systems are considered temporary or low stress installations and are not acceptable for use on ODOT projects.

11.4.7 Proprietary Flexible Rockfall Barrier Systems

High capacity rock fall net systems are available from two accepted manufacturers, GeoBrugg and Maccaferri. Full-scale tests on these systems have been performed by the manufacturers in accordance with European Technical Approval Guidelines (ETAN) 27. These guidelines were recommended for adoption by state DOT's in NCHRP Report 24-35 (2016). The systems are generally capable of withstanding impact kinetic energies up to 735 ft.-tons and can be constructed with breakaway post base connections and post heights up to 20 to 25 feet. Due to the proprietary nature of these systems, flexible rockfall barriers are typically procured using performance specifications that identify the design kinetic energy and roadway clear zones. These systems can be a viable alternative to high barriers and MSE walls in rock fall situations.

11.4.8 Pinned Cable and Wire Mesh Systems

Pinned cable and wire mesh systems are an effective rockfall mitigation alternative for mitigating rockfall where there is little or no catchment at grade and excavation is not an alternative. These systems can be designed as either passive or active. Passive systems do not apply a load to the slope and prevent rockfall by containing rocks behind the mesh. Examples of this approach include anchored cable nets. Active systems are installed in tension, which applied a normal load to the rock face and preventing rock fall from occurring. Pinned Tecco Mesh is an example of an active system. The designer must use the appropriate design approach and specifications associated with the intended mitigation.

11.4.9 Rock fall Attenuator Systems

Rock fall attenuator systems are a hybrid of drapery systems and flexible rock fall fences. They are typically designed to capture rock fall from sources substantially upslope of the roadway that are not practical to mitigate with drapery. The attenuator system attenuates the energy, suppresses the trajectory, and guides the rock to the base of the slope into the catchment area. A significant advantage to this system versus and upslope rock fall net system is that rock fall can be easily addressed by maintenance at ditch level.

The post-supported wire mesh slope protection included in ODOT Standard Details is an example of a low capacity attenuator system. This design should only be used for relatively small rock fall with modest trajectories and energies and its use confirmed through design. More robust attenuator systems are typically proprietary and procured using performance specifications. These designs should identify the design kinetic energy and location along the rock slope that the attenuator system should be placed.

11.5 Standard Details

Standard Details are normally used in the mitigation of rock fall hazards. These details are also found in the *Roadway Contract Plans Development Guide*. The following details are presented:

- Det 2200 - Cable Net Slope Protection
- Det 2201 - Wire Mesh/Cable Net Anchors

- Det 2202 - Shotcrete Slope
- Det 2203 - Wire Mesh Slope Protection
- Det 2204 - Barrier Mounted Rock Protection Screen
- Det 2205 - Post Supported Wire Mesh Slope Protection
- Det 2206 - Post Supported Wire Mesh Slope Protection
- Det 2207 – Post Supported Wire Mesh Slope Protection and Rock Protection Screen Anchor Details
- Det 2208 - Rock Protection Screen Behind Concrete Barrier or Guardrail
- Det 2209 - Rock Protection Screen Behind Concrete Barrier or Guardrail

11.6 Specifications

The location of Standard Specifications and Special Provisions for items pertaining to rock slopes and rock slope mitigation are listed in the next sections.

11.6.1 Blasting

Specifications for general excavation of rock slopes flatter than 0.75:1, where presplit (controlled blasting) of the backslope is not required, are located in *Section 00330.41(e) - Blasting of the Standard Specifications*.

Specifications for rock excavation where slopes are 0.75:1 or steeper are located in *Section 00335 - Blasting Methods and Protection of Excavation Back slopes of the Standard Specifications*. A per foot bid item quantity for Controlled Blast Holes is required if this specification is used.

Special Provisions for retaining a Blasting Consultant (see *Section 00335.44 Blasting Consultant*), Vibration Control (see *Section 00335.45 Vibration Control*), and Blasting Noise Control (see *Section 00335.46 Air blast and Noise Control*) are located in the Special Provisions section of the ODOT Specifications Webpage.

11.6.2 Rock slope Mitigation Methods

The following rock slope mitigation methods are located in a new section of the Standard Specifications, Section 00398 – Rock slope Stabilization and Reinforcement.

- Wire Mesh Slope Protection
- Post Supported Wire Mesh Slope Protection
- Rock Protection Screen Behind Barrier or Guardrail
- Rock Reinforcing Bolts/Rock Reinforcing Dowels
- Proprietary Flexible Rockfall Barrier System
- Pinned Wire Mesh

11.7 References

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